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Water to Nanofluids heat transfer in concentric tube heat exchanger: Experimental study

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Abstract

Concentric tube heat exchanger is a low cost, which increases reliability by restricting mixing of fluids exchanging heat. Concentric tube heat exchanger has potential application such as heat recovery from engine cooling circuit, oil cooling, desuperheating in refrigeration and air conditioning, dairy, and chemical industry, pharmaceutical industry, refinery, etc. This paper concentrate on an experimental study on concentric tube heat exchanger for water to nanofluids heat transfer with various concentrations of nanoparticles in to base fluids and application of nanofluids as working fluid. The experimental results on this type of heat exchanger configuration and water nanofluids could not be located in literature. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % nanofluids shown optimum performance with overall heat transfer coefficient 16% higher than water.

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Keywords: Nanofluids, Volume fraction, Energy, Overall heat transfer coefficient

Nomenclature

B position of
k Thermal conductivity

Greek symbols

Φ volume fraction

Subscripts

1 inlet
2 outlet
b base fluid
eff effective
o overall

1. Introduction

Heat recovery systems utilize heat exchangers to recover the waste heat. Addition of fins and increase of the heat transfer area are commonly applied to enhance the efficiency of the heat recovery system. However, these approaches lead to a

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larger and bulky heat exchanger. Kulkarni et al. [1] concluded that the usage of fins and micro channels have already reached their limit. The recent advances in nanotechnology have provided possibilities in advancing technology used in the heat exchanger. Argonne Laboratory developed new generation of heat transfer fluids that exhibit higher thermal conductivity known as nanofluids. Nanofluids are suspension of nanometer particles in a base fluid. Saidur et al. [2] reviewed comprehensively the possible applications of nanofluids in engine cooling, transformer cooling, machining process, and nuclear reactor cooling. It is normal and possible that, the performance of a heat recovery system can be enhanced by applying this advance heat transfer fluid.

This study attempts to investigate thermal performance concentric tube heat exchanger using nanofluids based coolants. The study covered thermal conductivity and convective heat transfer coefficient based performance of concentric tube heat exchanger.

1.1. Enhancement in thermal conductivity of nanofluids

Thermal conductivity is very important factor in convective heat transfer, since lower thermal conductivity of heat transfer fluids restrict cooling and heating performance. Large researcher is going on improving thermal conductivity of heat transfer fluids with addition of nanoparticles to it. Significant research suggests and considers nanofluids as replacement of existing heat transfer fluids. Khedkar et al. [3] reported thermal conductivity of water and ethylene glycol nanofluids with 5 % of CuO nanoparticles concentration enhanced 23 % compared to pure base fluids. Thermal conductivity of ethylene glycol based nanofluids with 0.3% concentration of copper enhanced up to 40% compared to that of the base fluid. Thermal conductivity of ethylene glycol based zinc oxide (ZnO) nanofluid enhances non-linearly with the addition of nanoparticle volume fractions [4]. Nanofluids thermal conductivity also depends on the nanoparticle size, volume fraction and temperature [5]. Study on grapheme was demonstrated by Yu et al. [6] and observed that thermal conductivity of ethylene glycol based nanofluids with 5 % grapheme can be improve 86% compared to that of the base fluid. Thermal conductivity of ethylene glycol based silver nanofluids increased up to 10%, 16% and 18% as the amount of silver nanoparticles was at 1000, 5000 and 10000 ppm, respectively [7].

1.2. Enhancement in convective heat transfer of nanofluids

Heris et al. [8] demonstrated convective heat transfer performance of water – alumina nanofluid in a circular tube under constant wall temperature. Results show that there is an enhancement of the nanofluid convective heat transfer coefficient with the increase of nanoparticle volume fraction. Experimentation on aqueous-based carbon nanofluid offers the highest enhancement of convective heat transfer compared to that of water based titanate and water based Titania nanofluids [9]. Duongthongsuk and Wongwises [10] studied that water based TiO₂ nanofluids experienced a slightly higher pressure drop with increased Reynolds number compared to that of base fluid in turbulent regime. Mohammed et al. [11] revealed that there is no significant pressure drop difference between water based alumina nanofluids and base fluid at lower Reynold's number in the micro channel heat sink.

2. Experimental

2.1. Nanofluids Preparation

In any nanofluids experimentation, preparation of stable and suitable nanofluid with low or no agglomeration of nanoparticles is the first step. In this study two step method is employed for synthesis of nanofluids. For the preparation of various nanofluids concentration, the alumina nanopowder was dispersed in water with the help of sonication. The alumina powders were added to double distilled water act as base fluids. Then, composition dispersed by magnetic stirring. The suspension was then homogenized by the application of a high intensity ultrasonic system (ChromTech Sonicator 1200 W). No surfactant was used in alumina water suspensions and sonication was employed for a period of time 2hr.

2.2. Thermal conductivity measurements

The thermal conductivity of alumina nanopowder and water with different concentration were measured with the help of transient hot wire based KD2 pro thermal analyzer. There are three different types of sensors available with this instrument for different materials and KS-1 sensor was used for the present measurement of thermal conductivity for nanofluids. This sensor needle can be used for measuring thermal conductivity of liquids in the range of 0.2–2 W/mK with an accuracy of $\pm 5\%$. Each measurement cycle consists of 90 s. During the first 30 s, the instrument will equilibrate which is then followed

by heating and cooling of sensor needle for 30 s each. Measurements were made for the volume fraction range of 1 % to 7.5 % addition of alumina nanopowder at constant room temperature.

2.3. Experimental setup for concentric tube heat exchanger and procedure

Fig. 1 shows the experimental setup for the investigating convective heat transfer characteristics of alumina – water nanofluids flowing through a horizontal concentric tube heat exchanger. The system mainly consists of two flow loops for nanofluid and heating fluid. It contains a concentric tube heat exchanger, heating section, a nanofluid reservoir tank (6 L), hot fluid reservoir tank and four thermocouples (K-type) with $\pm 0.1^\circ\text{C}$. error. For heat loss reduction to the surrounding the heat exchanger, pipe lines and reservoir's section are thermally insulated.

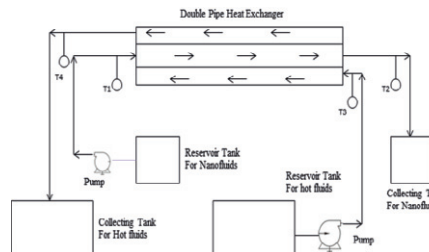


Fig. 1. Experimental setup for convective heat transfer study

The test section is the heat exchanger, in which nanofluids passes through the tube side with 6 mm inside diameter and 1000 mm length, while the hot fluid flows through the annulus side with a 16 mm inside diameter of outer pipe. The experimental condition of this study for both hot water and cold nanofluids were given in table 1.

Table 1. Experimental condition

Parameter	Hot fluid	Cold Fluids (Nanofluids)
Temperature	80	28
Flow rate	2 – 3 LPM	0.1 – 1 LPM
Reynolds Number	1000 – 3000	1000 - 5000
Volume concentration of nanoparticles	0	2 – 3 %

The thermal performance of nanofluid were analyzed on the overall heat transfer coefficient and thermal conductivity of nanofluids,

3. Results and Discussion

3.1. Thermal conductivity

Thermal conductivity of the water without addition of nanoparticles found to be 0.61 W/m K to confirm this value repetitive experimentation carried out on KD2 pro. Generally, the experiments showed that, addition of nanoparticles into the base fluids, an augmentation in thermal conductivity occurred. Similar effect is shown in alumina water composition (fig. 2). A plot shows the effects of nanoparticles concentration on the effective thermal conductivity and thermal conductivity ratio. It is important to notice that the particle concentration expressed in a volume fraction of nanoparticles. Water based nanofluid showing enhancement with the volume percent addition of nanoparticles. The greatest augmentation in thermal conductivity was found for 0.075 volume fraction nanofluids.

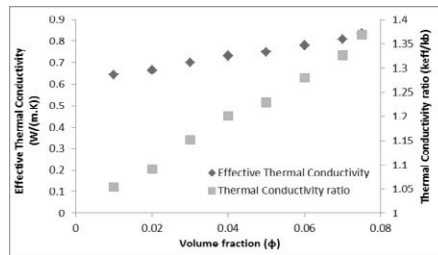


Fig. 2. Effective thermal conductivity and thermal conductivity ration as function of volume fraction

As the anoparticles concentration increase, particle to particle interaction increases results in decrease in distance in nanoparticles which become best explanation for enhancement in thermal conductivity with addition of nanoparticles.

3.2. Convective heat transfer

A heat transfer coefficient of the nanofluids (coolant) to the water has been calculated as the most indicative parameter. According to the Newton's cooling law, the rate of heat transfer between the wall of annulus and the coolant is

$$q = hA\Delta T \quad (1)$$

Where, q is the rate of heat governed in the hot water, h is convective heat transfer coefficient, A is heat transfer area, and ΔT_m is the Log mean temperature difference between the wall and the fluid in contact with the wall. The temperature of wall and hot water are assumed to be equal. The temperature of the nanofluids rises when passing through the inner pipe and therefore the heat absorbed by the coolant is

$$q = mC_{eff}(T_{out} - T_{in}) \quad (2)$$

The overall heat transfer coefficient, U_o , was calculated from the temperature data and the flow rates using the following equation

$$U_o = q/A_o LMTD \quad (3)$$

Where A_o is the surface area; q is the heat transfer rate; and LMTD is the log mean temperature difference, based on the inlet temperature difference, ΔT_1 , and the outlet temperature difference, ΔT_2 .

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \quad (4)$$

The heat transfer coefficients of all three test fluids determined by Eqs. (1)–(4) are plotted against volumetric flow rate in Fig. 3 and 4. It can be seen that the heat transfer coefficients increase as the volumetric flow rate. Under the same experimental condition, the heat transfer performance of the water as coolant in heat exchanger is apparently poorer to that of the 2 and 3 % nanofluids. And with the volumetric flow rate increasing, the differences in heat transfer coefficients between the water and nanofluids heat exchanger system become greater. In the operating range of this experimental investigation, heat exchanger with a the nanofluids as coolant yields a heat transfer enhancement over the water one of about 16 % for both 1.5 LPM and 3.5 LPM of hot fluid flow rate. From figure 3 and 4 it is observed that nanofluids heat transfer is obviously higher than water.

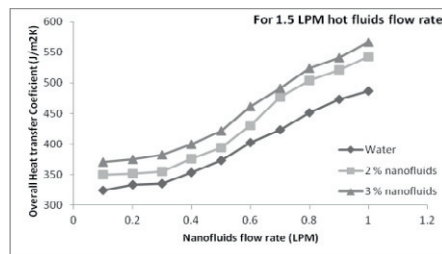


Fig. 3. Overall heat transfer coefficient against nanofluids flow rate for 1.5 LPM of hot fluids flow rate

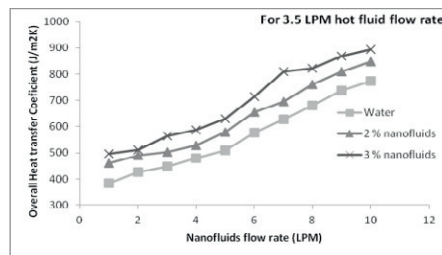


Fig. 4. Overall heat transfer coefficient against nanofluids flow rate for 3.5 LPM of hot fluids flow rate

Overall heat transfer performances study of concentric tube heat exchanger shows that thermal performance with nanofluids is higher than plain water as coolant, because in case of nanofluids heat transfer is enhanced with the support of nanoparticles and its properties.

4. Conclusion

Heat transfer study of double pipe heat exchanger with different volume fraction nanofluids has been experimentally evaluated. The heat transfer study was concentrated on thermal conductivity and overall heat transfer coefficient of Al_2O_3 based nanofluids. The conclusions of this study are as follows,

- The heat transfer coefficient of concentric tube heat exchanger with water shows poorer performance than nanofluids.
- The thermal conductivity enhancement is also observed with the addition of nanoparticles to pure base fluids.
- Nanofluids can be considered as next generation heat transfer fluids in heat transfer application.

Acknowledgements

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